INFLUENCE OF MOSCOW CITY ON THE AIR TEMPERATURE IN CENTRAL RUSSIA

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Abstract

The urban “heat island” effect in Moscow is being discussed. The mean annual air temperature in Moscow is higher at least on 1.5 ºC than outside of the city. The mean intensity of Moscow “heat island” is maximum in winter in the annual course and at night in the daily course. At noon in summer this effect seems to be almost vanished. Besides higher mean air temperature inside of city, the “heat island” leads to less standard deviation of it as well, especially in winter. The maximum intensity of the urban “heat island” in anticyclone conditions reaches up to 10-14 ºC. The weekly course of the air temperature is a probable phenomenon, connected with the “heat island”.

Key words: intensity of the urban “heat island”, daily course, weekly course, annual course

1. INTRODUCTION

The urban “heat island”, created by any city in a spatial field of the ground air temperature, is the most well known classic effect of the urban climatology. It was firstly founded by Luke Howard in London in 1820 and later was confirmed everywhere [1-4, etc.]. So, even the smallest town creates its own “heat island”. Usually the more is the city the more is the intensity of a “heat island”, that is the difference ?T between air temperature inside the city and outside it. There are some geographical particularities of ?T at various climatic zones. It seems to be generally more in Arctic climate and less in Tropic one [2,3]. As a rule, the maximum values of ?T can be observed in anticyclone conditions (followed by clear sky and calm) in the late evening or at night. In the afternoon ?T usually is minimal or even goes to nothing [1-4]. In moderate and Arctic climates the annual course of ?T is often noted by clear maximum in winter due to heating of a city [1-3]. The value of ?T clearly depends on a temporal averaging. The maximum ?T values for short time periods of several hours sometimes reach 10-12 ℃ and even more [3,4]. For long-term periods more than one year the average ?T consists of 0.5-1.5 ℃ in big cities [2,3].

It seems to be interesting to estimate ?T for Moscow city and test some mentioned above conclusions for the climatic conditions of Central Russia. So, this article is devoted to this purpose.

2. THE AVERAGE INTENSITY OF MOSCOW “HEAT ISLAND”

For investigations of a “heat island” Moscow city is suitable object because of its giant size, simple form like an almost ideal ellipse (see Fig.1) and nearly flat relief of Central Russia, which is situated inside of dry land at far from sea coasts. Thus, the urban “heat island” is expected to be clear effect here. For geographical analysis of its configuration and intensity we used the meteorological data of air temperature for period from 1951 to 1965. At that time the most amount of meteorological stations (nearly of 30) were operating in Moscow region. Later their number was reduced and now consists of only 20 stations approximately. That’s why the period of half a century ago was chosen for detailed cartography of Moscow “heat island”.

The maps of both annual, and mean January isotherms around Moscow city are shown in Fig.1. As one can see our capital clearly influences the air temperature field in Central Russia. At least one annual isotherm of +5 °C is localized as concentrated circle inside Moscow (Fig.1a). Indeed, the warmest station Balchug just in the center of city demonstrates mean annual temperature of +5.6 °C. Here a density of buildings and local heat sources is the highest in Moscow. According to the data of another five stations inside Moscow the mean annual temperature is nearly the same everywhere: either +4.5, or +4.6 °C. So, the intermediate isotherm of +4.5 °C marked in Fig.1a) as a dashed line is a concentrated circle as well around the city area. It should be noted that it has a tendency to be slightly replaced to the East due to Western flows dominating at the middle latitudes. Finally, we can see the next isotherm of +4 °C as a half-circle around Moscow, so there is a bend of it in front of the Western edge of the city. On the Western and Northern part of Moscow region the annual air temperature is slightly less (+3.7+3.8 °C) than on the Eastern one (+4.0+4.3 °C). So, Moscow city clearly depends on a spatial field of the annual air temperature by bending of the total +4 °C isotherm and creating an additional of +5 °C isotherm. The latter one seems to be a result only of city “heat island” because it can’t be supported here by any other climatic factors. It is interesting that the mean annual air temperature inside Moscow was equal to the +3.8 °C in the middle of the 19th century and to the +4.5 °C in the beginning of the 20th century [2]. So, the sharp increase in time of this parameter in Moscow exceeds total climatic tendency to warming in Central Russia.

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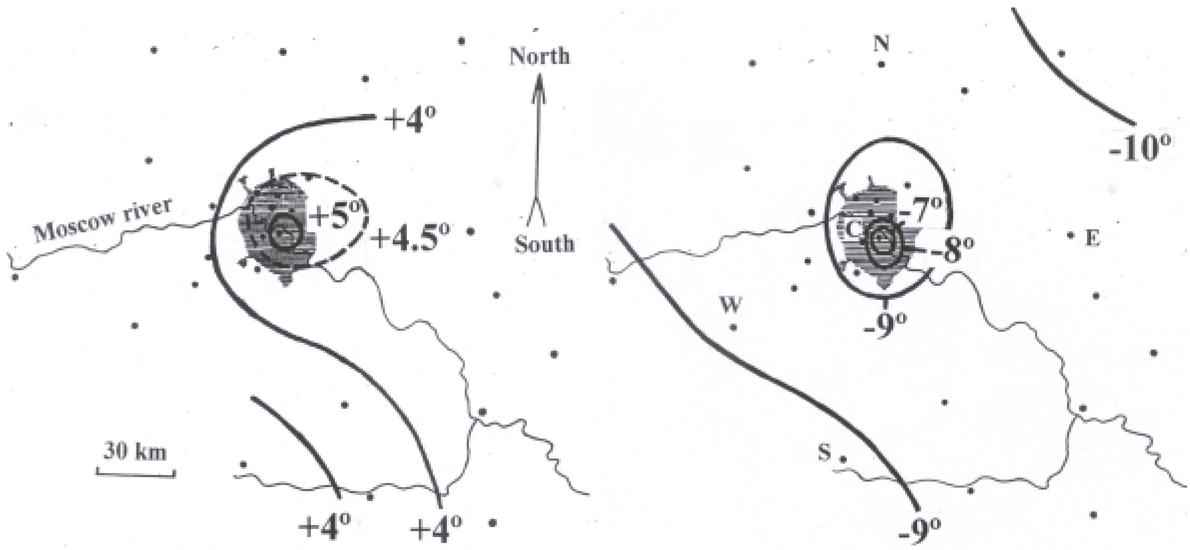


a) The annual air temperature **b) The mean air temperature on January**

Fig.1. The mean air temperatures in Moscow region for period 1951-1965, °C. Moscow city is a dashed area. Meteorological stations are marked by points.

Evidently, it is consequence of the urban "heat island" temporal dynamics.

So, in the middle of the twentieth century Moscow was warmer nearly on 1.5 °C in the comparison with its far suburbs. This value is inside of the range determined in [2] for selection of cities: since 0.5 till 1.5 °C. The similar estimation for Paris was received nearly the same too [3].

It is not a surprise that the effect of "heat island" in Moscow is the strongest in a cold season like in Calgary, Canada [3]. The map of mean isotherms for January here is presented in Fig.1b). As you can see, the contrast between city and rural zone sharply increased in the comparison with the annual isotherms. In the middle of winter there are already three concentrated isotherms around Moscow: –7, –8 and –9 °C. In Balchug the mean temperature in January consisted of –6 °C only whereas in rural surrounding of the city background temperatures varied in range from –9.1 to –9.5 °C everywhere.

3. THE MAXIMAL INTENSITY OF MOSCOW "HEAT ISLAND"

As for the most possible intensity of the urban "heat island", we selected and separately analyzed 30 cases of anticyclone weather in Moscow region with a clear sky and extremely low wind speed at various seasons in 2000-2002. Among all meteorological stations situated in Moscow city and in Moscow region the most differences between minimal nocturnal air temperatures T_{min} on two any stations have been detected as ?T_{min} at this night. It should be noted that the most value of T_{min} have been observed in all cases just in the center of Moscow, at Balchug station. Otherwise, the minimal T_{min} value has been occurred at various stations to the North and East of the city. As a result of this analysis, the average ?T_{min} for all 30 cases of clear anticyclone conditions was founded as nearly 8 °C. Several times the value of ?T_{min} reached 10-11 °C and once it even consisted of 13.6 °C. It happened in March the 26th, 2001, when the minimum air temperature in Balchug was equal to the –6.9 °C, whereas it was equal to the –20.5 °C in Klin, situated 80 km to the North from the city center.

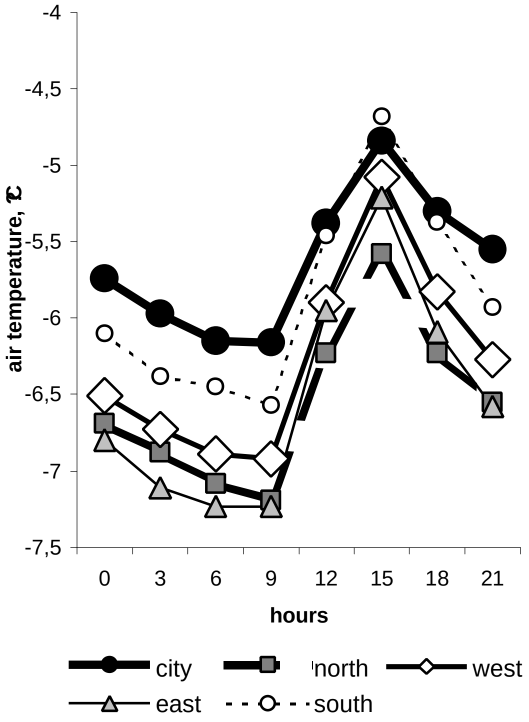
As it is known T.Oke suggested empirical functions connecting the maximal ?T_{min} and a city population both for Northern America and for Europe [3,4]. We have tested one of them (receiving for Canadian cities) with the account of population of Moscow (P = 8.500.000) and an average wind speed on 10 m height in a rural zone for these 30 cases (U = 1.8 m/s):

$$?T = P^{0.27} / (4.04 \cdot U^{0.56}) = 13.2\ (°C)$$

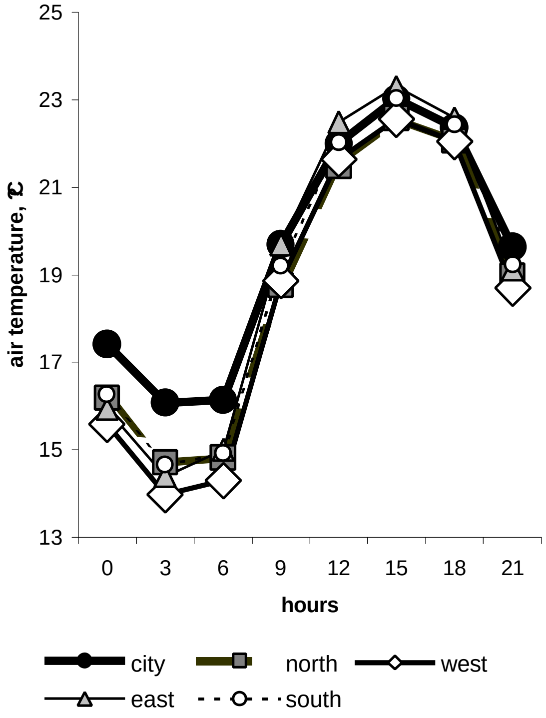
Thus, the result of calculation closely coincides the real maximum value of ?T_{min} in our selection: 13.6 °C. This fact confirms that climatic conditions of Russia and Canada are close to each other.

Evidently, real ?T may be still more than ?T_{min} because city area gets cool in the evening slower than rural zone. Indeed, in March the 26th, 2001 the value of ?T between the same two stations (Balchug and Klin) consisted of even 14.3 °C at 03 a.m., i.e. before coming of minimum nocturnal temperature.

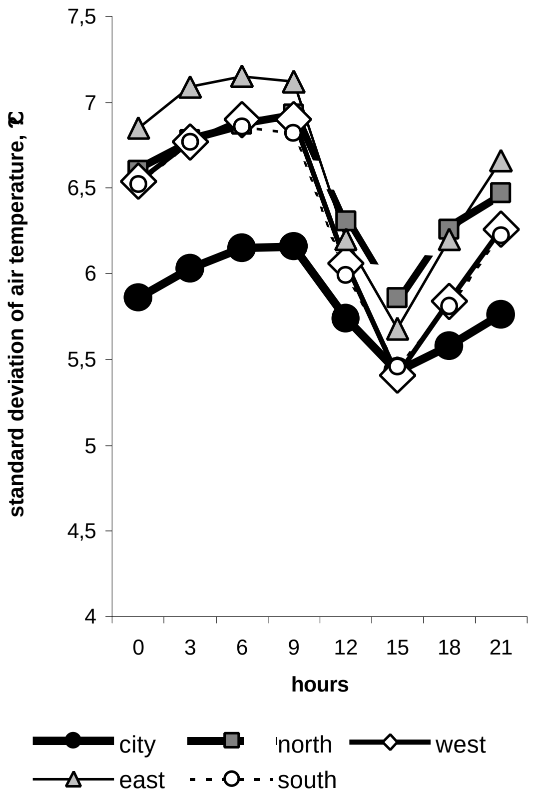
Thus, the most possible intensity of Moscow "heat island" can be more than 10 °C, sometimes even up to 14 °C. This value exceeds similar estimations made for separate days in Jena [1], Karlsruhe, Vienna [2], London [3], Vancouver [4], etc.



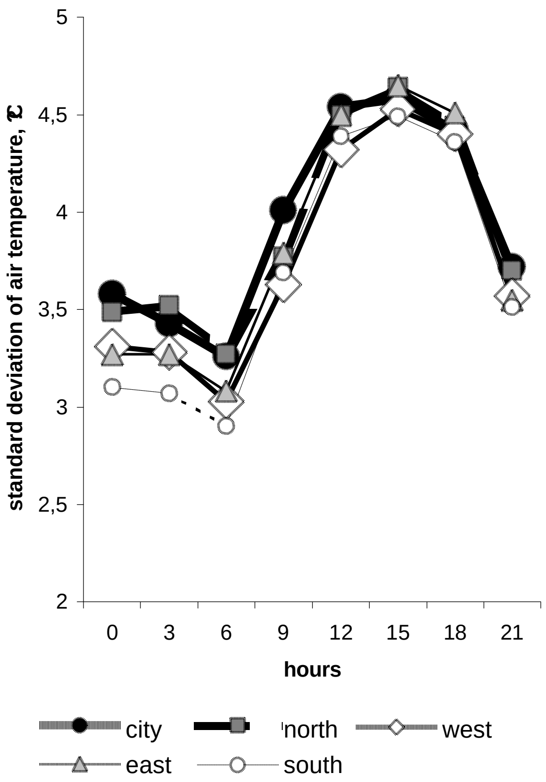
a) Mean air temperature in January, ℃



b) Mean air temperature in July, ℃



?) Standard deviation in January, ℃



d) Standard deviation in July, ℃

Fig.2. The mean and standard deviation values of the air temperature in Moscow and suburbs for period of 1991-2002, °C.

4. THE DAILY AND ANNUAL COURSES OF MOSCOW "HEAT ISLAND" INTENSITY.

For analysis of the air temperature daily course inside and outside of Moscow city the data of five stations for recent decade period from 1991 to 2002 has been used. These stations are marked in Fig.1b) by capital letters. One of these stations ("C") is our Moscow University situated in the southern-western periphery of Moscow city. In Fig.2 this data is shown as bold lines with big black circles. Unlike Balchug, it is not a central place of Moscow. However, it indicates the influence of the urban "heat island" as well. Other four stations roughly represent four possible directions at rural zone.

As one can see Moscow city in winter (Fig.2a) is much warmer at night than its suburbs. It is notably that the southern station Serpukhov (point "S") represents an intermediate position between the city and all other stations. Thus, the air temperature in Moscow in January is 0.5 °C higher than on the South and nearly of 1 °C higher than on the West, North and East from 9 p.m. to 9 a.m. It is evident as well that influence of city reduces at diurnal hours. At noon and at 6 p.m. the air temperatures in Moscow and on the South of Moscow region are nearly the same, whereas at 3 p.m. Moscow becomes even slightly cooler.

In summer (Fig.2b) differences between city and suburbs are much smaller than in winter. Only at night Moscow is obviously warmer than surrounding area at all directions. During the rest time the air temperature is nearly the same in July everywhere. So, we can conclude that Moscow "heat island" is more intensive both in winter in the annual course, and at night in the diurnal one. The first conclusion about the annual course is evidently confirmed both by Fig.1, and by Fig.2.

Besides, it is interesting to analyze standard deviations of the air temperature. As it is seen values of s(T) in Moscow are much smaller in winter than in suburbs, especially – at night. The most probable explanation of this effect is the influence of "heat island", preventing the city from extreme strong frosts. Hence, a scattering of possible air temperatures in Moscow is smaller than at rural areas because very low values do not occur inside the city. In summer differences of s(T) values between the city and suburbs seem to be negligible.

5.THE WEEKLY COURSE OF THE AIR TEMPERATURE IN MOSCOW

Another possible phenomenon connected with a "heat island" is the weekly course of some meteorological parameters. It is evident that only the human society divides time into intervals of seven days each. Hence, any clear and steady differences in weekly course of any parameter may be the consequence only of human activity. Usually a clear periodicity of 7 days has been founded in cities for concentrations of air pollutions like aerosol particles and for precipitation amount, which is connected with them [2]. However, sometimes even other meteorological parameters depend on a human activity and demonstrate the same periodicity as well, for example – the intensity of a "heat island" ?T [3].

In Fig.3 the mean annual air temperature, measured at Moscow University for period of 41 years (from 1961 to 2001) is shown be averaged per days of week. As it is seen, there is a clear weekly course having a maximum on Friday and minimum on Monday. In other words, the air temperature tends to arise during working-days. Vi?e versa, it reduces during weekend (Saturday and Sunday are non-working days both in former Soviet Union, and in Russia today).

The explanation of this effect seems to be physically simple. Evidently, direct heat emission from industry in city is negligible in the comparison of any other component of heat balance in atmosphere. However, indirect anthropogenic influence on the air temperature seems to be much more significant. For instance, the activity of industrial plants and traffic during working-days leads to increasing of a haze probability above the city, which reduces the effective infra-red radiation. As it is known the industrial haze is typical feature of the urban climate [2]. Hence, at the end of working-days period (i.e. on Friday) the air temperature at night may be slightly more than on other days. On Saturday and Sunday plants do not operate and traffic intensity sharply reduces as well. Hence, the industrial haze above city goes to nothing and nocturnal cooling of a ground becomes stronger. As a result, Monday statistically is the coolest day of the week. As it is seen, the mean difference between Friday and Monday consists of 0.28 °C. Separate recalculation of it only for cold season from November to March demonstrates even more value – 0.38 °C, whereas for warm season it was less: 0.23 °C. This effect is not surprising with account of more intense anthropogenic heating and more stable thermal stratification in winter, which leads to probable accumulation of a haze.

Of course, the accumulation of industrial haze during working-days is possible only in the calm conditions without any clear synoptic events, such as passing of fronts, etc. However, any other processes, being averaged per days of week for long-term periods, tend to their mutual compensation. That's why the anthropogenic effects became visible on Fig.3 due to an averaging for very long time. Even one year is too short period for statistical indication of this anthropogenic periodicity.

The significance of the air temperature weekly course has been tested. For this purpose the classic Student criterion has been used:

$\mathbf{Z = (\bar{X} - \bar{Y}) / \sqrt{s^2(X)/n + s^2(Y)/m}}$, where $\bar{X}$ and $\bar{Y}$ are mathematic expectations for two selections, that are

daily mean air temperatures for each Friday and each Monday from November to March during 41 years; $s^2(X)$ and $s^2(Y)$ are the dispersions of these selections, and $n = m = 887$ is their size. The calculated value of Z

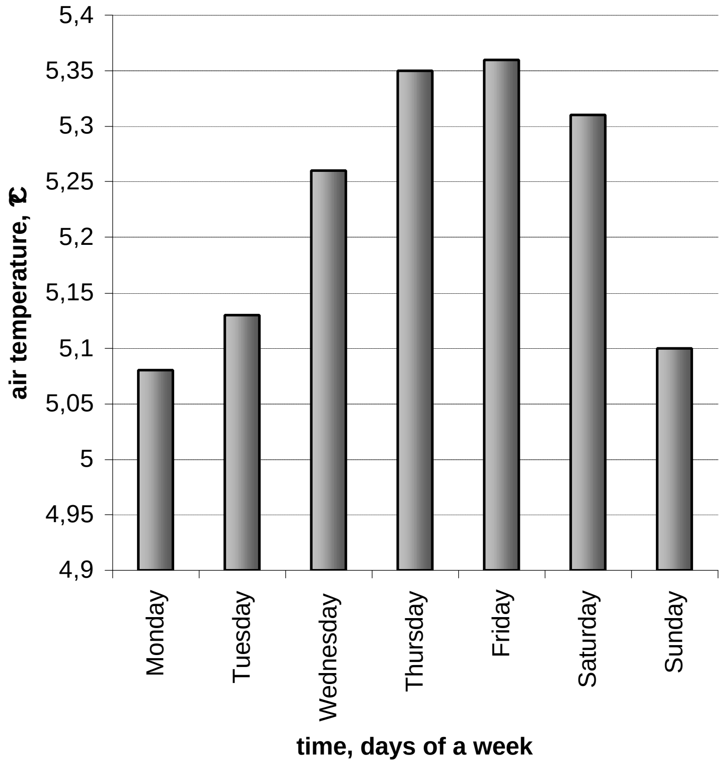


Fig.3. The weekly course of the mean annual air temperature at Moscow University for period of 1961-2001, °C.

consisted of 1.23 for a cold season. As it is seen, this value is less than the critical one (1.96) for the 5 % significance level according to Student criterion. Hence, the difference of 0.38 °C between both selected averages is not statistically significant for the 5 % significance level.

In spite of this result, we suggest Fig.3 for your attention as a hypothesis. Possibly, the effect of weekly periodicity of the air temperature will be confirmed later under more selection size. It should be noted that function in Fig.3 demonstrates only the single harmonic oscillation, and a total tendency from day to day is clear and coherent. Moreover, similar weekly effect for the ? T values was discussed in [3].

CONCLUSIONS

A “heat island” in Moscow is clear meteorological phenomenon as well as in other big cities. The intensity of it seems to be the most in a cold season and in nocturnal time all round the year. The mean annual air temperature in Moscow, at least some decades ago, was nearly of 1.5 °C higher than in suburbs. The maximum intensity of Moscow “heat island” can reach up to 14 °C. Possibly the air temperature in Moscow has a tendency to a weak weekly periodicity.

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